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ANTENNA SYSTEM FOR M-SAT MISSION

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ABSTRACT

Spar has evaluated and compared several antenna concepts for the North American Mobile Satellite.

The paper describes some of the requirements and design considerations for the antennas and demonstrates the performance of antenna concepts that can meet them.

Multiple beam reflector antennas are found to give best performance and much of the design effort has gone into the design of the primary feed radiators and beam forming networks to achieve efficient beams with good overlap and flexibility. Helices and cup dipole radiators have been breadboarded as feed element candidates and measured results are presented.

The studies and breadboard activities have made Spar ready to proceed with a flight program.

INTRODUCTION

Since the late 1970's Spar Aerospace Limited has studied and evaluated different concepts and payload designs for a Canadian Mobile Communication Satellite (M-SAT). These studies have been funded by the Canadian Department of Communication and have been aimed towards the design of a demonstration model. Growing commercial interest in both the USA and Canada has changed the program into an industry led commercial program. From being a UHF band system the concept evolved into a combined L and UHF band system in 1986. The WARC conference in 1987 established the L-band as the frequency band for mobile satellite service and M-SAT is now an L-band only system.

Spar has had a leading role in defining system requirements and proposing suitable designs. Reference 1 describes the baseline system requirements. It is assumed that two identical spacecrafts, one US and one Canadian, each operated independently, would enable a commercial system to be implemented by the early 1990's. This first generation system would allow mutual backup in the event of a spacecraft failure.

This paper describes some of the antenna configurations and hardware that have been and are considered for the M-SAT space segment.

ANTENNA REQUIREMENTS AND CONSIDERATIONS

The space segment of a mobile satellite communication system must provide high power densities (EIRP) on the ground to allow mobiles with small, low gain, antennas to communicate. The limited spectra allocated for mobile services requires maximum possible frequency reuse. The user distribution is uncertain and will vary during the satellite lifetime. There is thus a need to have flexibility in spectrum and power allocations over the coverage region.

High gain spot beam antennas are well suited to meet these requirements. Electrically the challenge is to design a multiple beam antenna system with good beam overlap, low sidelobes and high efficiency, that also allows for flexibility. Mechanically the challenge is to provide large antenna apertures meeting the mass and volume constraints of the spacecraft. Mesh reflector suppliers have achieved good performance with breadboarded reflectors and associated deployment hardware.

Spar has systematically studied and evaluated suitable antenna candidates, several of which are described in the next section. All reflector concepts assume offset reflector with 5m projected aperture.

ANTENNA CONFIGURATIONS

9-Beam 15 Shared Feed Element Reflector Antenna Concept

Nine beams are generated by a 15 element feed cluster. The beams share feed elements to get good overlap and antenna efficiency. Typically 4 feeds with uniform excitation are used for each beam. The feed cluster layout is shown together with the resulting coverage in Figure 1.

The minimum coverage directivity is 33.0 dBi based on calculations assuming cup dipole primary radiators. Frequencies can be reused every third beam with 22 dB isolation.

Low level beam forming and distributed amplifiers are used to facilitate the excitation. Power flexibility can be achieved by combining varying numbers of power modules or by varying the collector voltage of a fixed size amplifier. However, this flexibility results in lower power efficiency and has implications on weight and complexity.

9-Beam 11 Shared Feed Element Reflector Antenna Concept

The region of interest can be covered by the same number of beams with fewer feed elements with just a slight reduction in coverage gain. The feed cluster layout is shown in Figure 2 with the corresponding coverage. Typically 4 feed elements are used for each beam. Two beams are generated by the same 4 feeds using reciprocal non uniform excitation in the North-South direction i.e., for the US and Canada beams. The beams share feed elements in the East-West direction in order to achieve good beam overlap. The resulting coverage directivity is 32.5 dBi except for small areas in the South of the USA. Frequencies can be reused every third beam with 20 dB isolation.

A low level beam forming system similar to the one described in the previous section can also be used here.

This antenna concept is the main candidate for M-Sat.

9-Beam Independent Feed Element Reflector Antenna Concept

This concept utilizes one feed element per beam so that no beam forming is required. The feed element must be physically small to achieve the desired beam separation. Small feed elements result in low efficiency because of high spillover losses. Spar has investigated the use of cup dipole radiators and helix radiators for this concept. Despite the high aperture efficiency of the cup dipole the minimum coverage directivity is only 30.5 dBi. The helix radiator has an effective aperture that is larger than its physical area and can thus be placed closer together to achieve better beam overlap. Closely spaced helices have strong interaction (mutual coupling) and their radiation patterns are greatly affected. However, the performance can benefit from mutual coupling effects as the active patterns can be shaped to have very flat top and steep fall-offs. Figure 3 shows a layout of the helix cluster and the achieved coverage contours. Frequencies can be reused every third beam with 18 dB isolation. The coverage is calculated using measured primary patterns of helices located in their representative feed cluster environment.

The coverage directivity is 32 dBi except for a small corner in the south of the USA. This is 1.5 dB better than what can be achieved with cup dipole radiators, but still 0.5 dB lower than for the main candidate system. However, excitation errors of the shared feeds reduces the gain difference to about 0.3 dB.

The independent feed per beam concept significantly reduces the complexity and weight of the transponder and feed assembly. No beam forming networks are required and the number of radiators, filters and amplifiers is reduced. This concept is considered as a good candidate for a low cost system.

Direct Radiating Array Antenna Concept

The advantage of a direct radiating array with scanning beams is the increased flexibility. The beams can be scanned to increase the gain in specific areas either due to changed traffic requirements or a change in orbital location. Beams can also be repointed to compensate for failure of an amplifier or of a complete beam.

One of the antenna candidates studied is a 5.1 x 4.5 m hexagonal direct radiating array. The radiating elements used are high efficiency short backfire radiators. A total of 127 elements are arranged in 23 groups, each powered by a separate amplifier. The groups are formed such that the amplifiers are loaded with equal power. The power is distributed within each group using a low loss TEM line network. With this design concept the target area is covered by 9 scannable beams each with its variable low level beam forming network.

The grouping of the elements and the associated non ideal phase excitation makes the outermost beams less efficient resulting in a minimum coverage directivity of 32.3 dBi.

The main drawback of using a hexagonal direct radiating array is the complex deployment scheme required and the weight of the antenna. The mass and complexity also make it impossible to have separate transmit and receive antennas which increases the risk of distortions caused by passive intermodulation. A hexagonal direct radiating array is thus not seen as an attractive option for M-SAT. However, a rectangular array as described in reference 2 can be implemented and offers good flexibility.

Imaging Reflector Antennas Concept

Single and dual reflector imaging antennas with electronic beam scanning have also been investigated.

The single reflector imaging system is realized using a reflector and a relatively small feed array. The feed array is located between the reflector and the focal point. This way, the field distribution of the feed array is approximately recreated over the reflector aperture and a scan of the feed array results in a proportional scan of the antenna.

A dual reflector imaging system comprises a main reflector, a sub-reflector, and a feed array. The sub-reflector is located in the near field of the feed array and the reflectors are arranged confocally such that a magnified image of the array is formed over the main reflector aperture (3). Compared to a direct radiating array the number of radiators is smaller which leads to a simplification of the beam forming network and a substantial reduction of the mass of the array itself. A large array can hardly be folded while a large deployable reflector can be stowed in a relatively small volume compatible with launcher envelopes. It is also feasible to have separate transmit and receive antennas.

Both systems were optimized using a 5 m diameter main reflector. The dual reflector imaging system resulted in a minimum coverage directivity of 31.6 dBi compared to 31.2 dBi for the single imaging system. The sidelobe performance of the imaging systems is poor, reducing the possibility of frequency reuse. Imaging antenna systems are thus not considered a very attractive option.

RADIATOR DEVELOPMENT

Cup Dipole Radiator

A cross dipole with unequal arm lengths fed by a split-coax balun and placed inside a circular or a square cup provides a simple and efficient circularly polarized radiator for narrowband applications. The cup dipole radiator is thus a very good candidate for the M-SAT primary feed radiators. Table 1 presents measured data for three different cups over the M-SAT transmit frequency band 1530 - 1559 MHz.

Helix Radiator

Helices have been investigated as feed elements, especially for the independent beam configuration. In particular, the effects of mutual coupling between helices in an array have been studied.

The helix test model uses an 8 turn copper plated steel spring conductor which is supported by a high density polystyrene cross support. The helix circumference is 1.1λ . Four tapered turns are used to improve the axial ratio performance. The helix is placed in a circular cup whose diameter and depth are experimentally determined to optimize mutual coupling effects. The measured axial ratio on-axis is better than 0.2 dB for the isolated helix and better than 1 dB for a helix in a cluster. Figure 4 compares the radiation patterns of an isolated helix, and the same helix in a 6-element cluster. The active pattern has lower peak gain but has a flat top which makes it efficient as a primary radiator for a reflector. The test results together with the secondary pattern calculations demonstrate that helices can be used efficiently as independent feed elements for multiple beam antennas.

CONCLUSION

Desirable features of antenna systems for Mobile Communication Systems have been defined and a number of suitable antenna designs have been described.

The performances of the candidate concepts have been systematically evaluated by Spar and some of the major considerations are given in this paper. The 9 beam shared feed horn reflector concept with 11 feed elements is presently considered to be the best approach. This system offers efficient beams with good overlap, sidelobes that allow frequency reuse, good power flexibility and separate transmit and receive antennas. Design and evaluation of concepts are continuing as the system requirements are becoming more well defined.

Some hardware has been developed to support the conceptual designs. Test results from cup dipole and helix radiators are presented here. Both radiators show more than adequate performance for M-SAT requirements.

Spar is also co-operating with mesh reflector suppliers and has performed tests of a 5 m mesh reflector together with Aerospatiale. Similar tests will be performed with MBB during 1988.

REFERENCES

[1] Hing, K. et al. Considerations for spacecraft design for M-Sat. paper to be presented at The Mobile Satellite Conference JPL 1988

[2] Rosen, H. Frequency Addressable beams for Satellite Communications. Telcom 87 Geneva

[3] Dragone, C. Gang, M.J. Imaging reflector arrangements to form a scanning beam using a small array. The Bell System Technical Journal. Vol. 58, No. 2, February 1979.

Table 1. Cup Dipole Performance

	EFFICIENCY %	AXIAL RATIO [dB]			RETURN LOSS [dB]		
		1530	1545	1559 MHz	1530	1545	1559 MHz
Circular cup 0 = 1.3λ	99	1.8	0.8	1.2	-27	-29	-31
Circular cup 0 = 0.65λ	97	0.4	0.3	0.3	-16	-20	-21
Square cup d = 0.65λ	97	0.5	0.4	0.2	-17	-25	-24

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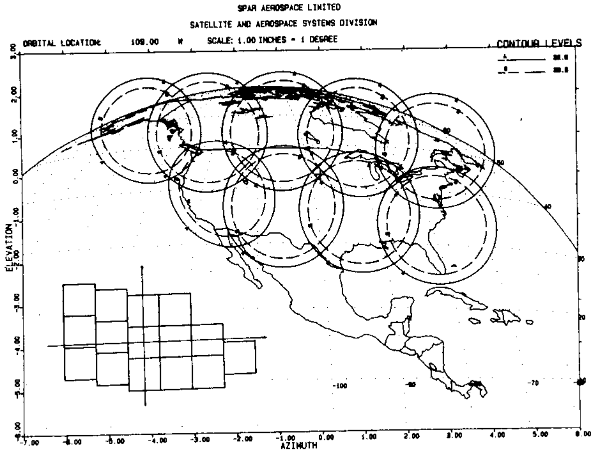

Figure 1 Coverage with 15 Shared Feed Elements

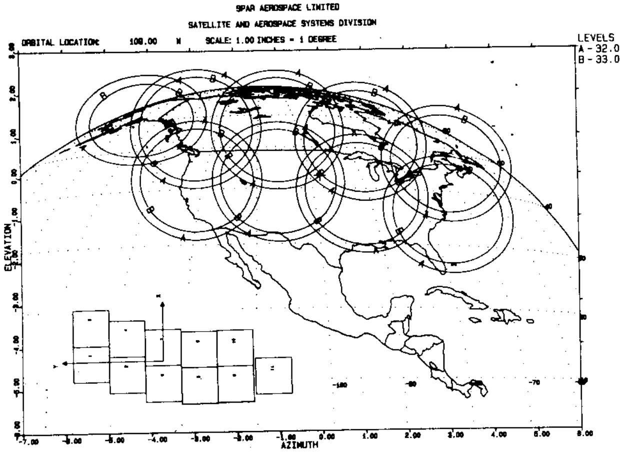

Figure 2 Coverage with 11 Shared Feed Elements

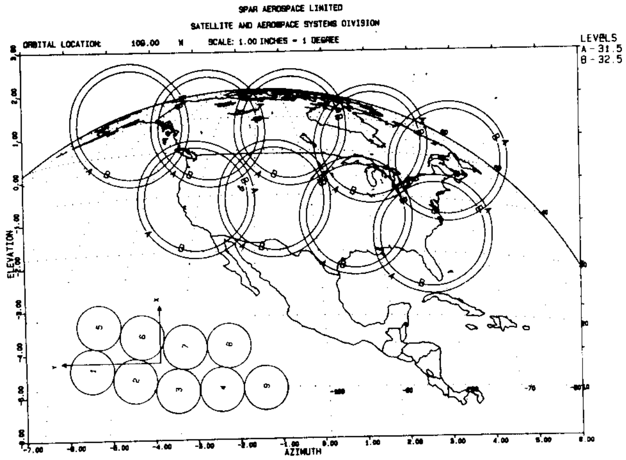

Figure 3 Coverage with 9 Independent Helix Feed Elements

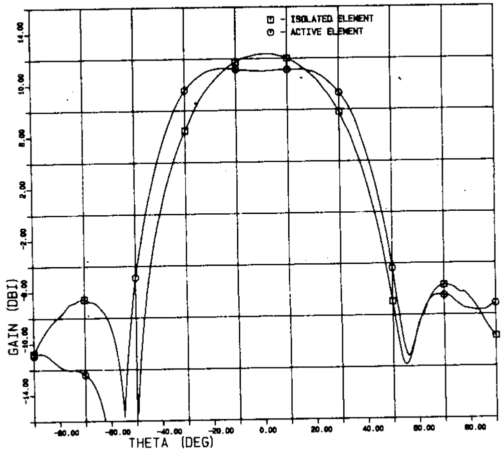

Figure 4 Helix Radiation Patterns